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This is a request for filing a PROVISIONAL APPLICATION FOR PATENT under 37 CFR 1.53(c).

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INVENTOR(S)

Given Name (first and middle [if any])	Family Name or Surname	Residence (City and either State or Foreign Country)
JIANGLEI	MA	KANATA, ONTARIO, CANADA

Additional inventors are being named on the ONE *separately numbered sheets attached hereto*

TITLE OF THE INVENTION (500 characters max)

PILOT DESIGN FOR OFDM SYSTEMS WITH FOUR TRANSMIT ANTENNAS

Direct all correspondence to: **CORRESPONDENCE ADDRESS**

☑ Customer Number: 021498

OR

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ENCLOSED APPLICATION PARTS *(check all that apply)*

☑ Specification *Number of Pages* 10

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☐ Application Data Sheet. See 37 CFR 1.76

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☐ Other (specify) ______

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Respectfully submitted,

SIGNATURE John D. Crane

TYPED or PRINTED NAME JOHN D. CRANE

TELEPHONE 972-685-8442

Date MARCH 15, 2004

REGISTRATION NO. 25,231
(if appropriate)
Docket Number: 16867ROUS01P

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Docket Number	16867ROUS01P

INVENTOR(S)/APPLICANT(S)

Given Name (first and middle [if any])	Family or Surname	Residence (City and either State or Foreign Country)
MING	JIA	OTTAWA, ONTARIO, CANADA
WEN	TONG	OTTAWA, ONTARIO, CANADA
PEIYING	ZHU	KANATA, ONTARIO, CANADA

Number ONE of ONE

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Provisional Patent Application

Title:

Pilot Design For OFDM Systems With Four Transmit Antennas

Inventors:

Jianglei Ma, Kanata, Ontario, Canada
Ming Jia, Ottawa, Ontario, Canada
Wen Tong, Ottawa, Ontario, Canada
Peiying Zhu, Kanata, Ontario, Canada

Submitted:

March 15, 2004

Pilot Design for OFDM Systems with Four Transmit Antennas

For an OFDMA system it contains two types of pilot signals

- Scattered pilot
- Preamble pilot

We present novel pilot structure for 4x4 MIMO OFDM system.

1. PART-1 SCATTERED PILOT

1.1 BACKGROUND

New applications of mobile communications demand high-speed and high-quality, bandwidth-efficient wireless access solutions. The application of MIMO (multiple antennas both in the transmitter and in the receiver) has been demonstrated to drastically improve the channel capacity compared to single-antenna systems. On the other hand, OFDM has demonstrated its high spectral efficiency and ability to deal with frequency selective fading and narrow band interference. Therefore the combination of OFDM with spectral efficient multiple antenna techniques open the door to high data-rate wireless communication.

Compared with the single input single output (SISO) systems, two kinds of gains are provided by the MIMO wireless systems, the diversity gain and the multiplexing gain. With diversity gain more reliable reception can be realized. With multiplexing gain the capacity of MIMO systems increases linearly with the number of transmit and receive antennas. This is due to the fact that a rich scattering environment can provide multiple data pipes within the same frequency band by using techniques such as space-time coding and space-time layering. Since the capacity can be potentially increased by the application of multi-antenna, the use of up to 4 antennas at the transmitter and/or receiver has been considered to achieve the increased data rate for a given link performance criterion, or the improve link performance for a given data rate.

For wireless propagation environment, the inherent temporal and spatial variations of wireless channels impose more challenges on the design of a reliable communication system. For noise and interference limited systems coherent demodulation can achieve 2.5-3 dB SNR gain compared to the differential demodulation. When coherent detection is performed in Rx, reliable channel estimation is very important to the system performance. Channel estimation in MIMO system is more complicated because multiple channels should be obtained individually. Besides as the number of transmit antennas increases, the sensitivity to the channel response estimation error is more pronounced.

Pilot assisted channel parameter estimator is a common channel estimation approach. In this contribution, we propose the training signal designs for different propagation environments, especially for OFDM systems with four transmit antennas.

1.2 PRIOR ART

OFDM modulation has been adapted by several standards, such as DVB-T, IEEE802.11a/g and IEEE802.16a. Different training schemes have been employed in these standards, including preamble, fixed-location pilot and variable-location pilot. However MIMO is not mandatory and is only adapted by IEEE802.16a as optional where only two transmit antennas on the BS side and one receive antenna on the SS side are applied. Since IEEE802.16a is designed for fixed and portable applications, the channel varies slowly. For WirelessMan OFDM air-interface, the channel estimation is obtained from the preambles. For WirelessMan OFDMA air-interface, although variable location pilots are introduced, they are

only used to update channel slowly. Figure 1. and Figure 2 give the pilot locations for WirelessMAN-OFDM and WirelessMAN-OFDMA.

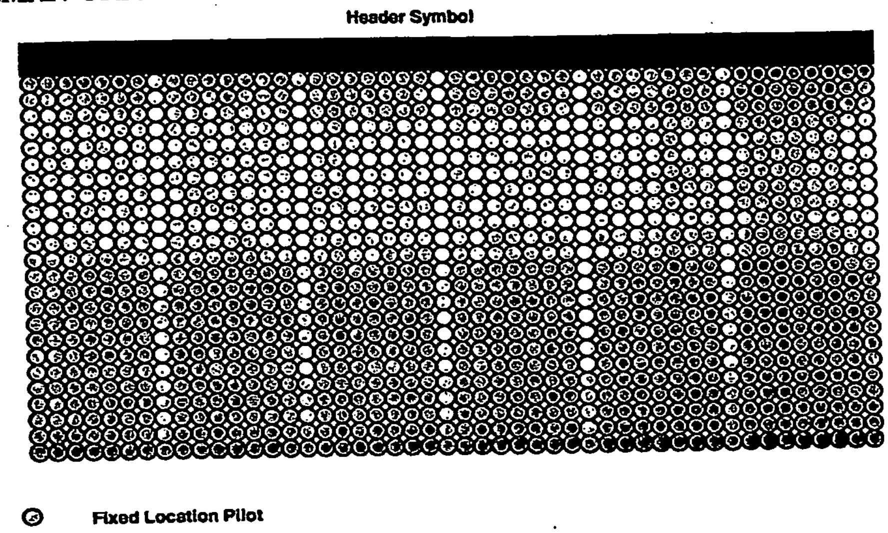


Figure 1 SISO OFDM pilot structure

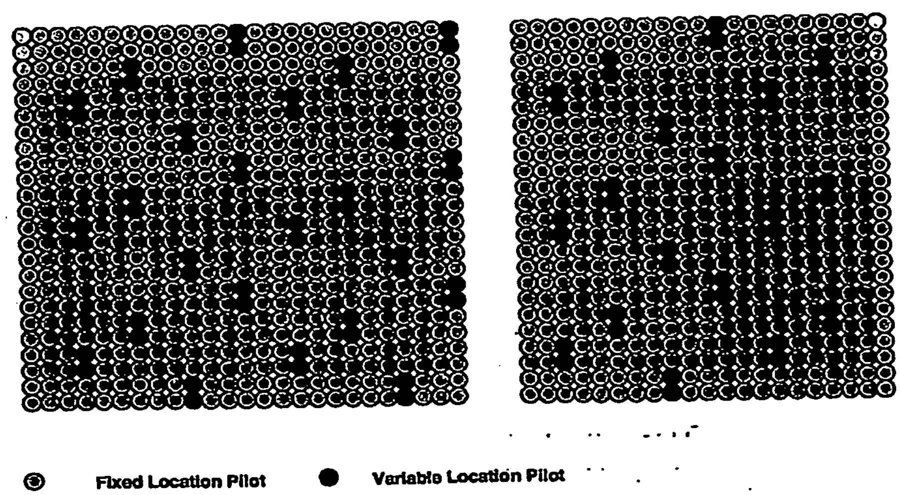


Figure 2 MIMO OFDMA pilot structure

Nortel has proposed more optimal pilot design for mobile MIMO-OFDM system with two transmit antennas. The key features in this scheme are:

- Pair-wise pilot sub-carriers corresponding to different transmit antennas are STTD coded, as shown in figure 3. In this way, the orthogonality between the pilots assigned to different transmit antennas are kept. The advantages of this design is that channel response estimated from STTD coded pilot pair reflects the averaged channel condition of two OFDM symbol duration.
- The diamond pattern of scattered pilots allows the simple and fast channel interpolation which can track the fast channel of the channel.

- The reuse of differential STC encoded TPS channel reduces the pilot overhead.

For 4x4 MIMO-OFDM system operating in TDD mode across very broad bandwidth (license-exempt band), the old designs have some limitations:

- More efficient pilot pattern is required because 4x4 channel estimation needs doubled pilot resource compared with 2x2 systems.
- To support TTI slot based TDD switching, TTI slot based channel estimation scheme is required.
- The increased sub-carrier separation caused by the bandwidth increase means higher pilot density is needed along frequency direction

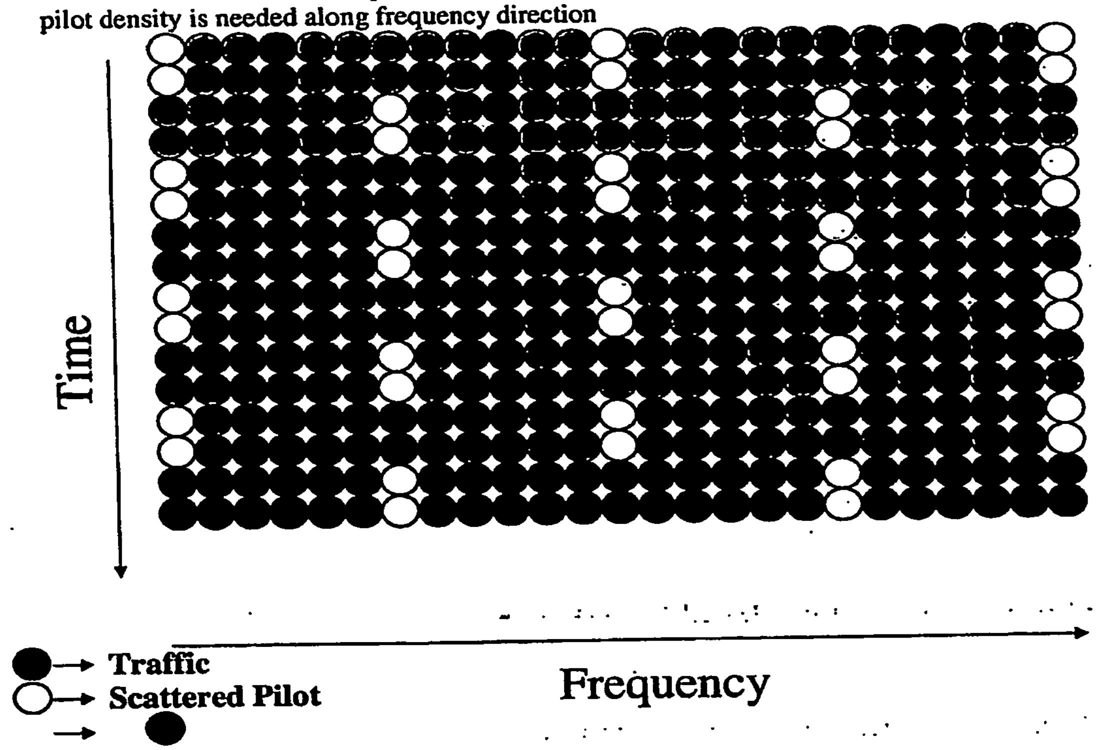


Figure 3 2x2 MIMO pilot structure

1.3 EMBODIMENT

Coherent detection is required to achieve high spectrum efficiency. Pilot assisted channel estimation is a widely applied approach to measure the change of the amplitude and phase of the transmitted signals caused by the corruption of the radio channel.

For pilot-assisted channel estimation the known training symbols are multiplexed into the data stream at certain sub-channels (sub-carriers) and certain times. The receiver interpolates the channel information derived from the pilot symbols and obtains the channel estimates for the data symbols.

However, the training symbols introduce the overhead. For the channel with both frequency and time dispersion, pilots have to be inserted both in frequency and time direction. The spacing between pilots in time direction is determined by the maximum Doppler frequency, while the spacing between pilots in the frequency direction is determined by the delay spread of the multi-path fading. For broadband mobile access application, the channel should be updated more frequently both in frequency direction and in time direction in order to obtain

the correct channel responses across the while bandwidth during the whole transmission period. The high frequency and time dispersions demand denser pilot grid, which means more overhead is needed. Compared to SISO systems, four times more pilot symbols are required for 4x4 MIMO systems.

Moreover TDD deployment put further limitation to the design of the pilot pattern. To support slot-based TDD switching, channel estimation processing should be performed slot by slot, i.e. the channel responses should be calculated only based on the pilot symbols in the current slot.

Figure 4 shows an example of the proposed design. The main ideas are described as bellows:

- Four antennas are separated into two groups, for example Antennas 1&3 as group 1 and Antennas 2&4 as group 2.
- Two sets of the scattered pilots are introduced for each group.
  - No overlap between two pilot sets in time and frequency
- The pilot positions are kept identical from even to odd OFDM symbols.
  - Space-time-block-coding (STBC) block may be applied on each pilot pairs
    - Double STTD, OTD-STTD
  - The scattered pilot pairs shifted every two OFDM symbols (one STBC block) repeating every 6 OFDM symbols (three STBC blocks)
- TPS symbols are reused to reduce the pilot overhead.
  - STBC applied on TPS symbols
  - TPS symbols decoded coherently with the help of the adjacent pilots
  - Re-encoded TPS symbols served as pilots in the detection of the data symbols

Simple and fast channel estimation may be done based on the above pilots.

- Extract the received frequency domain data located at the pilot and TPS sub-carriers corresponding to each pilot set respectively
- Calculate the channel responses for two transmit antennas in each antenna group based on the received pilot data and the known sequences transmitted by pilot sub-carriers and the re-encoded TPS
- Buffer all channel responses within one slot.
- Obtain the channel responses of sub-carriers located at the same position as pilots by linear interpolator in time direction
- Obtain the channel responses of the data sub-carriers at the boundaries (including those at the first and last sub-carriers in each OFDM symbol and on the first and last OFDM symbols in each slot) by repeating the channel responses of the adjacent pilots
- Apply simple 1-D interpolation, for example Cubic Lagrange interpolator, to reconstruct the entire channels

If multiple TDD slots assigned to DL, channel estimation performance may be improved by applying the pilots/re-encoded TPSs in the last two BLAST blocks in the previous TDD slot and/or the first two BLAST blocks in the next TDD slot to assist the channel response interpolation for the current slot.

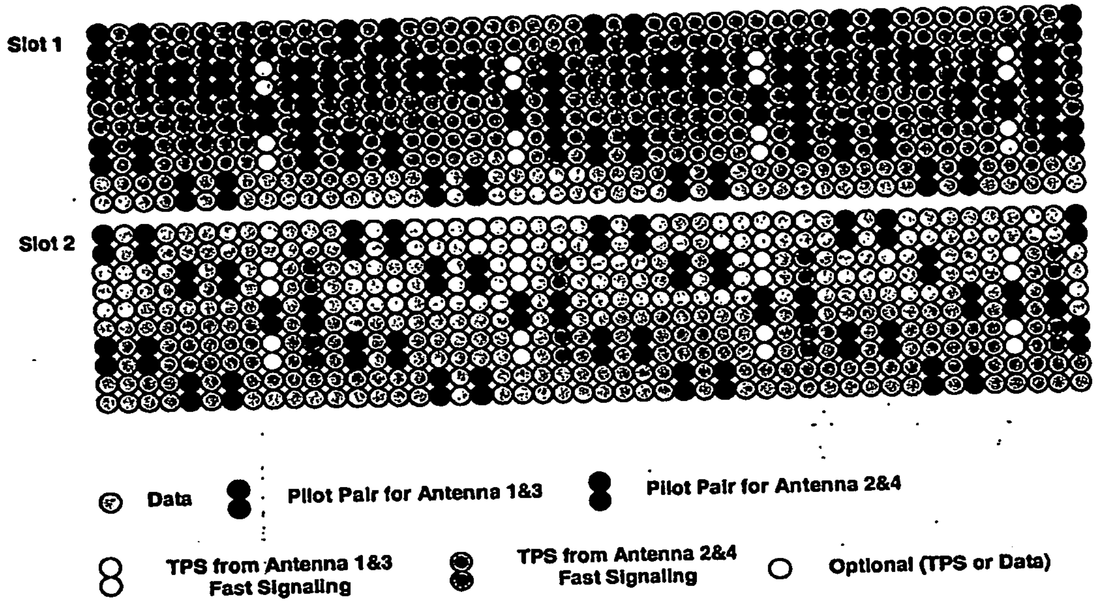


Figure 4 4x4 MIMO pilot structure

It should be noticed that several other scattered pilot patterns can also be used in this invention. Figures 5, 6, 7, 8 are examples.

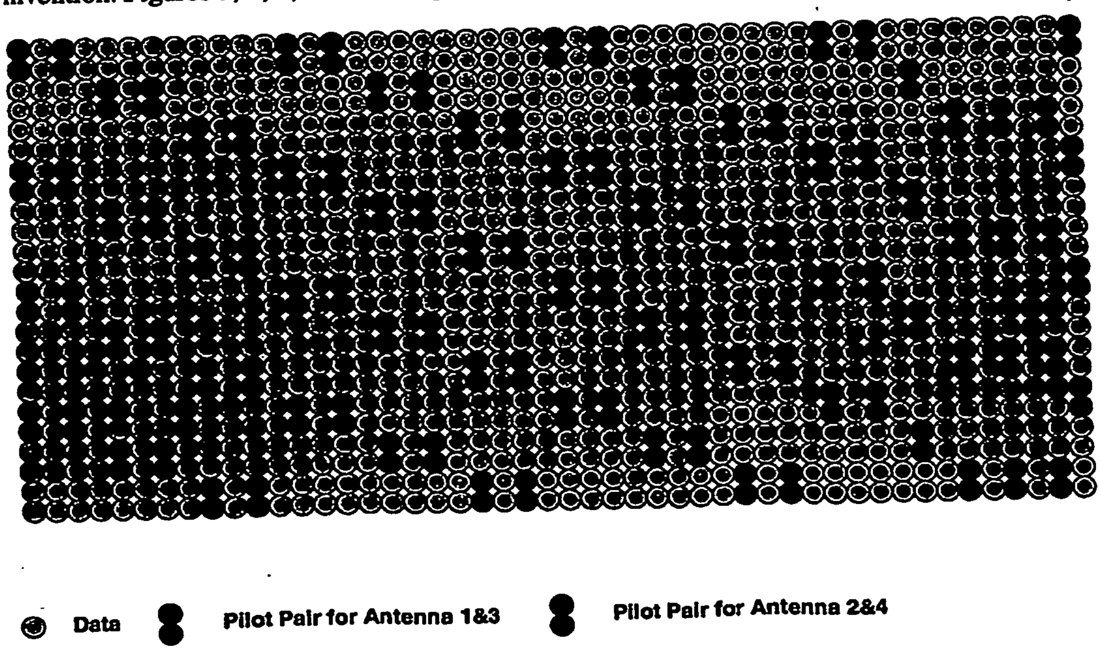
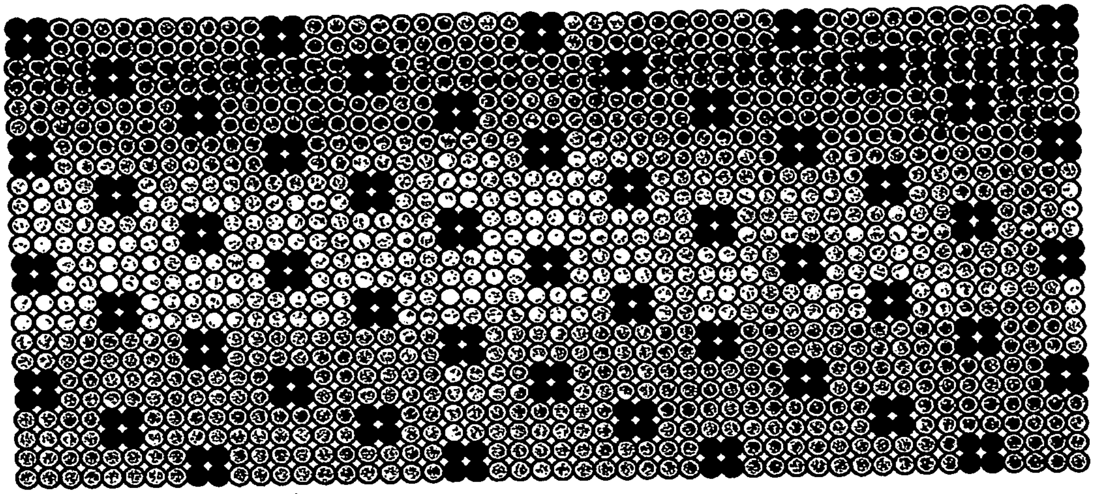
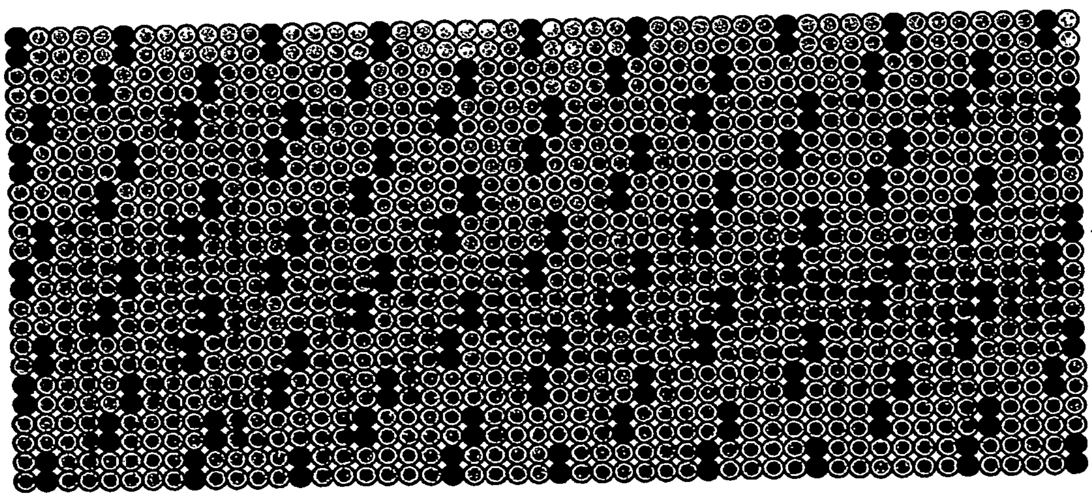


Figure 5



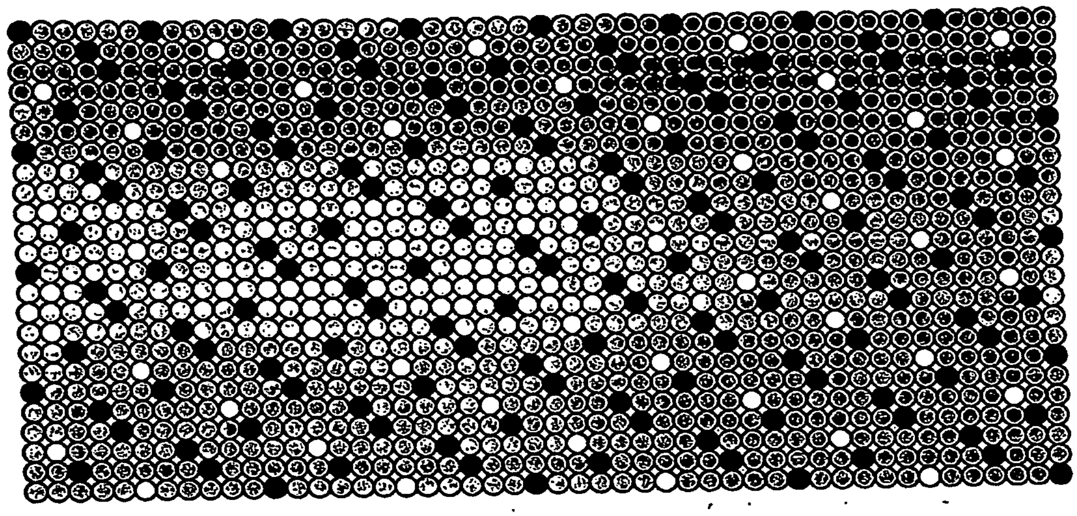
Data Pilot Pair for Antenna 1&3 Pilot Pair for Antenna 2&4

Figure 6



Data Pilot Pair for Antenna 1&3 Pilot Pair for Antenna 2&4

Figure 7



Data Pilot Pair for Antenna 1 Pilot Pair for Antenna 2

Pilot Pair for Antenna 3 Pilot Pair for Antenna 4

Figure 8

1.4 SUMMARY OF ADVANTAGES

- Efficient scattered pilot pattern reduces the pilot overhead, especially for transmit systems with four transmit antennas
- Slot by slot channel response interpolation supports flexible TDD UL and DL partition.
- Slot by slot channel response estimation reduces the buffering requirement and the processing delay.
- Unique fast signaling channel allows the extraction of TPS every TTI slot
- Fast signaling channel reuse further reduces the pilot overhead
- Support broad band high-speed mobile access

2. PART-2 PREAMBLE PILOT

Preamble is transmitted at the beginning of the DL transmission in each frame. The preamble consists of two identical header symbols, the time domain structure of the preamble is shown in Figure 5.

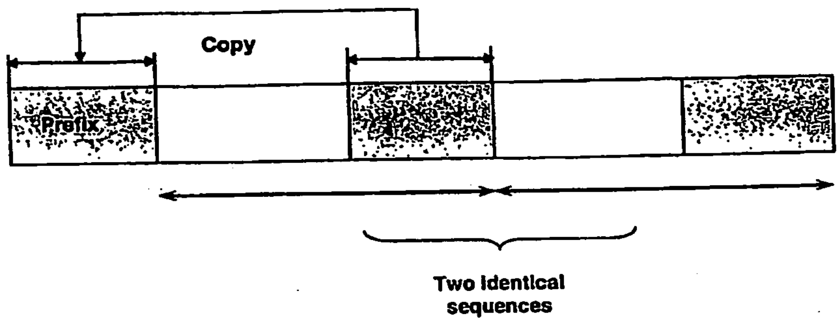


Figure 5

It is desirable that the antennas the transmissions from different antennas is orthogonal, to achieve better performance of initial system access, synchronizations, base station identification and selection, channel estimation

2.1 Two modulation scheme for preamble

2.1.1 Scheme 1

- Separate 4 antennas into two groups
- SFBC (space-frequency block coding) is applied to each group
- For slow frequency selective fading channel
- Two head symbols are identical

The preamble structure schem-1 is shown in Figure 6

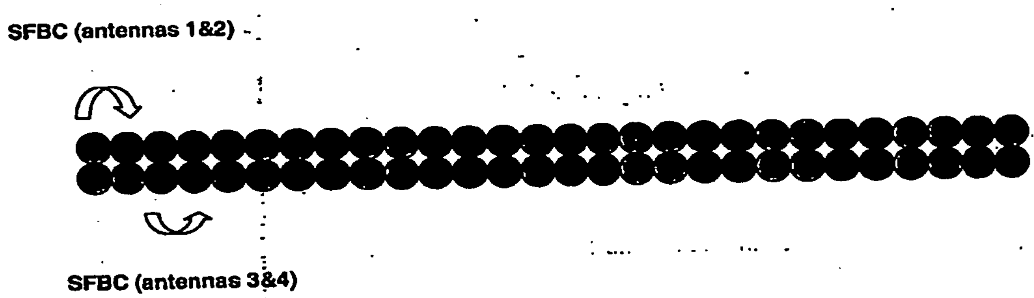


Figure 6 Preamble structure – (1)

The preamble specific PN sequence mapping is as follows:

Transmit sequence from antenna 1:
PN(1), –PN(2)*, PN(5), -PN(6)*, ……, PN(N-3), –PN(N-2)*

Transmit sequence from antenna 2:
PN(2), PN(1)*, PN(6), PN(5)*, ……, PN(N-2), PN(N-3)*

Transmit sequence from antenna 3:
PN(3), –PN(4)*, PN(7), -PN(8)*, ……, PN(N-1), –PN(N)*

Transmit sequence from antenna 4:
PN(4), PN(3)*, PN(8), PN(7)*, ……, PN(N), PN(N-1)*

PN sequence is cell specific code (real or complex) and N is the number of useful sub-carrier in header symbol.

2.1.2 Scheme 2

- Each antenna modulate every four sub-carriers
- Two head symbols are identical

Channel information obtained from preamble can be used for coherent detection of the next OFDM symbol used for broadcasting channel

The preamble structure schem-1 is shown in Figure 7

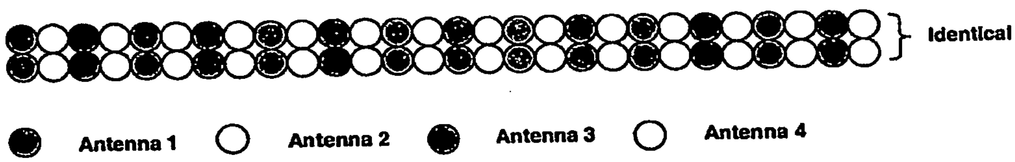


Figure 7 Preamble structure – (2)

The preamble specific PN sequence mapping is as follows:

Transmit sequence from antenna 1:
PN(1), PN(5), ……, PN(N-3)
Transmit sequence from antenna 2:
PN(2), PN(6), ……, PN(N-2)
Transmit sequence from antenna 3:
PN(3), PN(7), ……, PN(N-1)
Transmit sequence from antenna 4:
PN(4), PN(8), ……, PN(N)

PN sequence is cell specific code (real or complex) and N is the number of useful sub-carrier in header symbol.

2.2 SUMMARY OF ADVANTAGES

- Support OFDM system with four transmit antennas
- The orthorgonality between different antennas allows channel estimation for multiple transmit antennas
- Allow fast system access, timing/frequency synchronization and base station identification/selection